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VOLUMETRIC AND PHASE BEHAVIOR OF MIXTURES OF NITRIC OXIDE AND NITROGEN DIOXIDE

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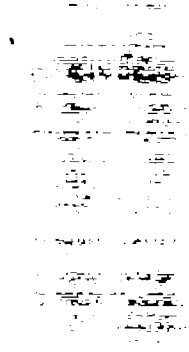
ABSTRACT

The oxides of nitrogen are potentially useful as oxidants in special fuel systems. Mixtures of nitric oxide and nitrogen dioxide are particularly promising because of the lower freezing point which results from the addition of small quantities of nitric oxide to nitrogen dioxide. A knowledge of the volumetric and phase behavior of mixtures of nitric oxide and nitrogen dioxide is of utility in the design of equipment for the storage and delivery of these compounds to combustion equipment.

The compositions of the coexisting phases of mixtures of nitric oxide and nitrogen dioxide were established throughout the two-phase region for temperatures above 70° F. and for compositions containing more than 0.80 weight fraction of nitrogen dioxide. The specific volumes of the liquid and gas phases of mixtures of these oxides were determined at temperatures between 40° F. and 340° F. for pressures up to 7,000 pounds per square inch. The results are presented in tabular and graphical form.

The bubble point pressure of mixtures of these oxides of nitrogen containing as much as 0.2 weight fraction of nitric oxide is below 300 pounds per square inch at 160° F. Such pressures are low enough to permit the use of conventional means of storage and handling of the

mixtures of the oxides of nitrogen under most climatic conditions. The specific volume changes almost linearly with isobaric-isothermal change in composition in both the liquid and the gas phases, thus permitting ready interpolation of the results to any desired composition within the range of investigation. The data obtained are consistent with measurements already available for the volumetric and phase behavior of the pure components.



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INTRODUCTION

The phase behavior of mixtures of nitric oxide and nitrogen dioxide has not been studied at elevated pressures. Epstein and Cirkova (3) determined the two-phase pressures of mixtures of these oxides of nitrogen containing as much as 0.38 weight fraction of nitric oxide at temperatures between 68° F. and 140° F. for pressures below 240 pounds per square inch. The compositions of the mixtures investigated were related to the earlier measurements of Baume and Robert (1), who studied this binary system at temperatures below 68° F. Wittorf (19) determined the limits of solubility of nitric oxide in nitrogen dioxide in the same range of temperature as was reported by Baume and Robert. Purcell and Cheesman (9) measured the solubility of nitric oxide in nitrogen dioxide at temperatures below 51° F. for pressures less than 68 pounds per square inch. Whittaker and coworkers (17) determined the two-phase pressure for six mixtures of nitric oxide and nitrogen dioxide for compositions containing up to 0.169 weight fraction of nitric oxide. The measurements were made at temperatures between -40° and 59° F. Their results are in reasonable agreement with those of Baume and Robert (1).

The effect of pressure and temperature upon the specific volume of

the components has been investigated in some detail. Briner and coworkers (2) established the volumetric behavior of nitric oxide at low temperatures and Johnston and Weimer (6) determined the second virial coefficient at temperatures up to 70° F. for pressures below one atmosphere. Recently the volumetric behavior of this compound was studied at pressures up to 2,500 pounds per square inch for temperatures between 40° and 220° F. (4).

Verhoek and Daniels (16) and Mittasch and coworkers (8) determined the volumetric behavior of nitrogen dioxide in the gaseous region for temperatures below 113° F. Scheffer and Treub (12) measured the vapor pressure of this compound up to the critical temperature. Recently additional measurements have extended the knowledge of the volumetric behavior of the liquid and gas phases of this compound to temperatures of 340° F. and pressures up to 7,000 pounds per square inch (10, 13). Kobe and Pennington (7) recently reviewed the thermochemical characteristics of nitrogen and its oxides.

The present measurements are concerned with the volumetric behavior of 15 mixtures of nitric oxide and nitrogen dioxide at compositions containing as much as 0.2 weight fraction nitric oxide at pressures up to 7,000 pounds per square inch in the temperature interval between 40° and 340° F. Four of these mixtures were investigated in detail and the remainder were studied throughout the indicated temperature interval at nearly a single specific volume. The dew point and bubble point states for four mixtures were determined as a function of temperature.

METHODS

The methods employed in this investigation were similar to those described earlier for the study of the volumetric behavior of nitrogen dioxide (10,13). In principle, they involved the containment of the mixture in a spherical pressure vessel (10). The pressure within this vessel was determined by means of a pressure balance (11) which was connected to the vessel through a liquid-filled tube terminating at the sphere with a stainless steel diaphragm (10, 13). This balance was calibrated against the vapor pressure of carbon dioxide at the ice point. The pressures were established within 0.2 pound per square inch or 0.1%, whichever measure yielded the larger uncertainty.

The pressure vessel was immersed in an agitated temperature-controlled bath of a silicone and the temperature was measured by means of a platinum resistance thermometer which had been compared recently with a similar instrument calibrated by the National Bureau of Standards. These comparisons were made with such care and the temperature of the bath was so steady that the temperature within the working vessel was known relative to the international platinum scale with a probable error of 0.03° F.

The weight of each of the components was determined gravimetrically by the use of weighing bomb techniques (11). The total quantity of sample originally introduced was established with a probable error of not more than 0.03% and the compositions of the mixtures were known with a standard error of 0.0012 mole fraction. After each set of measurements of a sequence of corresponding pressures and temperatures, a portion of the sample was withdrawn at a state in the single-phase region

and another sequence of pressures and temperatures was then determined. A total of from five to ten series of such measurements were made with each of the four mixtures. In the end the entire sample was withdrawn and the cumulative weights of the mixture removed were compared with the original weight. In each case it was found that the weight of the oxides of nitrogen withdrawn agreed within 0.1% with that added. Such agreement was one more indication of the relatively small uncertainty in the weights of the material involved in the several sets of measurements.

Phase boundaries for the mixtures were established from discontinuities of the pressure-temperature derivatives which occurred at these points. The specific volume of the mixtures at each of the states investigated was determined from the weight of the material within the pressure vessel and the total volume of the container. The latter value was established from calibrations with a known weight of liquid water at relatively low pressures for a series of temperatures. The studies of Smith and Keyes (15) were employed to determine the specific volume of water as a function of pressure and temperature. The changes in volume of the container with pressure and temperature were ascertained from the thermal expansion and Young's modulus of the steel. The spherical shape and nearly uniform wall thickness permitted the changes in volume to be established with accuracy. Excellent agreement was obtained between the variation in volume of the pressure vessel with temperature established from the calibration with water and that predicted from the thermal expansion of the steel. Deviations of as much

as 0.15% in the volume of the spherical pressure vessel at pressures above 7,000 pounds per square inch were found between the values established from the volumetric behavior of water (15) and those predicted from Young's modulus of the steel and the volume of the vessel at low pressures. In the present study the specific volumes of the mixtures were based upon the total volume of the pressure vessel at 70° F. and atmospheric pressure and the properties of the steel. It is believed that the specific volumes were known with a standard error of 0.18% throughout the ranges of pressure and temperature investigated.

MATERIALS

The nitric oxide utilized in this work was obtained from The Matheson Co. and was purified by the method described by Johnston and Giauque (5), involving absorption of impurities and subsequent fractionation and sublimation. The specific weight of a sample of the purified gas at atmospheric pressure indicated that it probably contained less than 0.002 weight fraction of material other than nitric oxide. The nitrogen dioxide, obtained from the Allied Chemical and Dye Corp., was purified by fractionation at atmospheric pressure in a glass column containing 16 plates. The fractionation was carried out at a reflux ratio of 10 and the middle 60% of the overhead was retained for final purification. This partially purified material was passed over phosphorous pentoxide at a pressure of one atmosphere and condensed at the temperature of liquid nitrogen at a pressure below 0.001 inch of mercury. The vapor pressure of the purified nitrogen dioxide was in good agree-

ment with earlier values (13). It is believed that it contained less than 0.003 weight fraction of material other than nitrogen dioxide. The purified samples of the oxides of nitrogen were stored at pressures higher than atmospheric in stainless steel containers until used.

EXPERIMENTAL RESULTS

Typical sets of pressure-temperature measurements for mixtures containing 0.8312 and 0.8205 weight fractions of nitrogen dioxide are shown in Figures 1 and 2 respectively. Figure 1 presents data for the gaseous region, whereas those in Figure 2 relate to the liquid region. The data in the heterogeneous region have been omitted in the interest of clarity. The pressure-temperature diagram of Figure 3 portrays on a somewhat larger scale the behavior, near the boundaries of the heterogeneous region, of a mixture containing 0.9431 weight fraction of nitrogen dioxide. The precision of the data shown is typical of that obtained in this study. A series of four such sets of measurements together with measurements for a single pressure-temperature sequence with each of 11 mixtures formed the experimental basis for the present results. A detailed record of the experimental determinations is available (14). A sample of this information constitutes Table I in which the pressure, temperature, and specific volume have been recorded for each of the states investigated. Because of the small change in total volume of the bomb with varying conditions, a corresponding change in the specific volume of the sample recurs. In Figures 1, 2, and 3 the

average specific volume for each of the pressure-temperature sequences has been depicted.

Figure 4 presents the compressibility factor as a function of pressure for a mixture containing 0.8312 weight fraction of nitrogen dioxide. The values of the compressibility factor were computed in the following way:

$$Z = \frac{PVM^*}{RT} = \frac{PV}{bT} \qquad (1)$$

The constants in Equation 1 were based upon an atomic weight of nitrogen of 14.008 and an atomic weight of oxygen of 16.000 which correspond to the values recommended in a tabulation of atomic weights (18). A value of the universal gas constant of 10.73185 (lb. per sq. in.) (cu. ft. per lb. mole) per °R. was employed. Table II records the values of the specific volume and compressibility factor for five evenly spaced compositions within the range of the conditions which were covered in the investigation, using even values of pressure and temperature. The effect of composition upon the specific volume of this system in the liquid phase at a temperature of 160° F. is shown in Figure 5. Figure 6 presents a compressibility factor-composition diagram for a temperature of 280° F., including data at low pressures.

Figure 7 is a pressure-composition diagram for the bubble point liquid and dew point gas for the lower temperatures. The curves have been extended only over the range of compositions for which experimental measurements were obtained. The compositions of the gas phase coexisting

with liquid reported by Purcell and Cheesman (9) were interpolated to 40° F. and were taken into account in the preparation of this diagram.

Figure 8 depicts the pressure-composition relations for the higher temperatures. The behavior is much simpler for temperatures above 100° F. and the data may be interpolated with but small uncertainty. Table III records the properties of the coexisting liquid and gas phases as a function of pressure and temperature. The information recorded in this tabulation was obtained by graphical interpolation of the volumetric measurements available.

ACKNOWLEDGMENT

This investigation was supported by the Office of Naval Research L. T. Carmichael and G. N. Richter contributed to the experimental program and Virginia Berry assisted in the preparation of the data in a form suitable for publication. The Naval Ordnance Test Station, Inyokern, made available the nitrogen dioxide used in this program. W. N. Lacey reviewed the manuscript.

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NOMENCLATURE

b	specific gas constant
M*	average molecular weight
P	pressure, lb./sq. inch absolute
R	universal gas constant
T	absolute temperature, $^{\circ}R$
V	specific volume, cu. ft./lb.
Z	compressibility factor

FIGURES

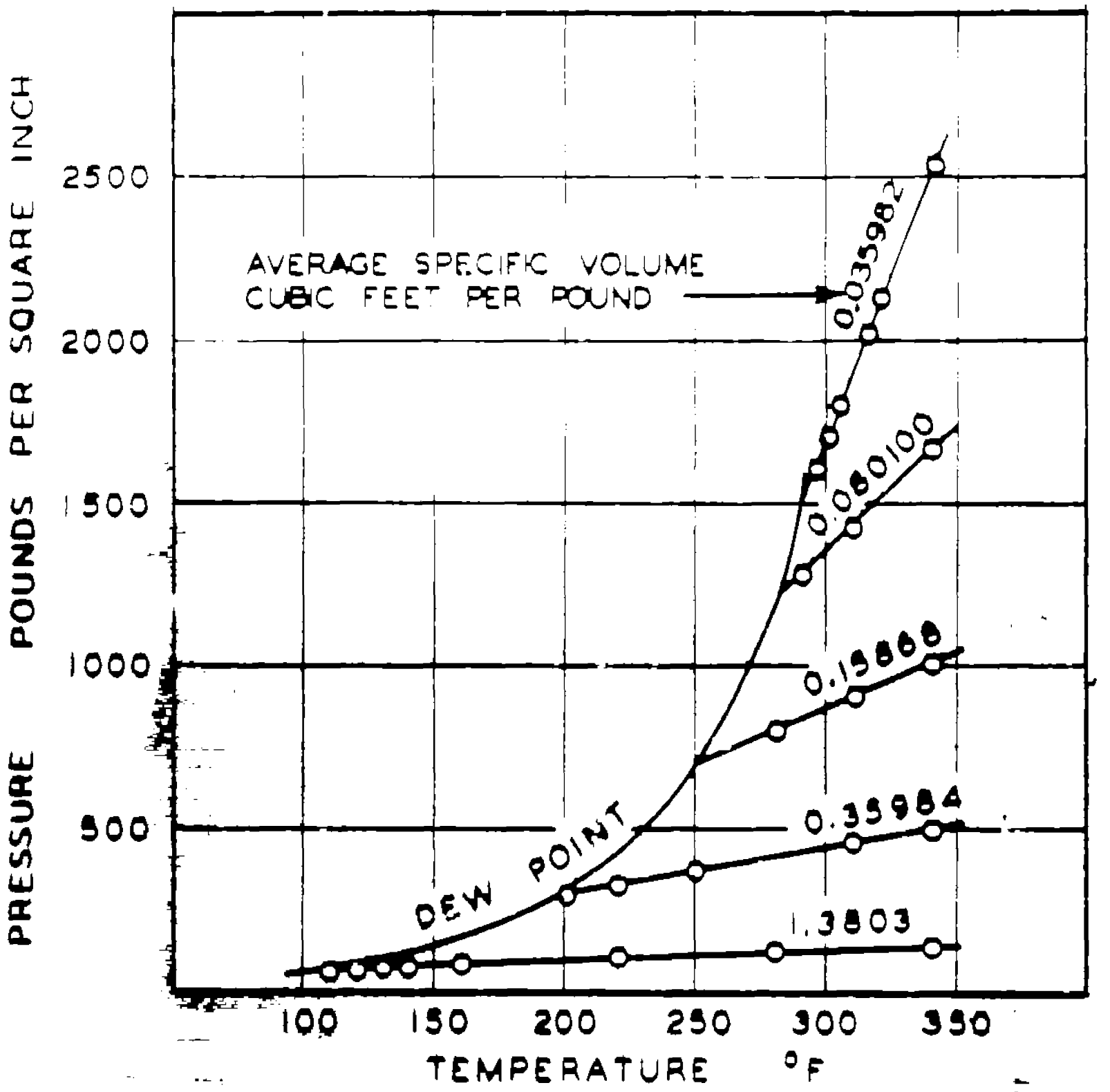

Fig. 1 Pressure-Temperature Diagram for a Mixture Containing 0.8312 Weight Fraction Nitrogen Dioxide.

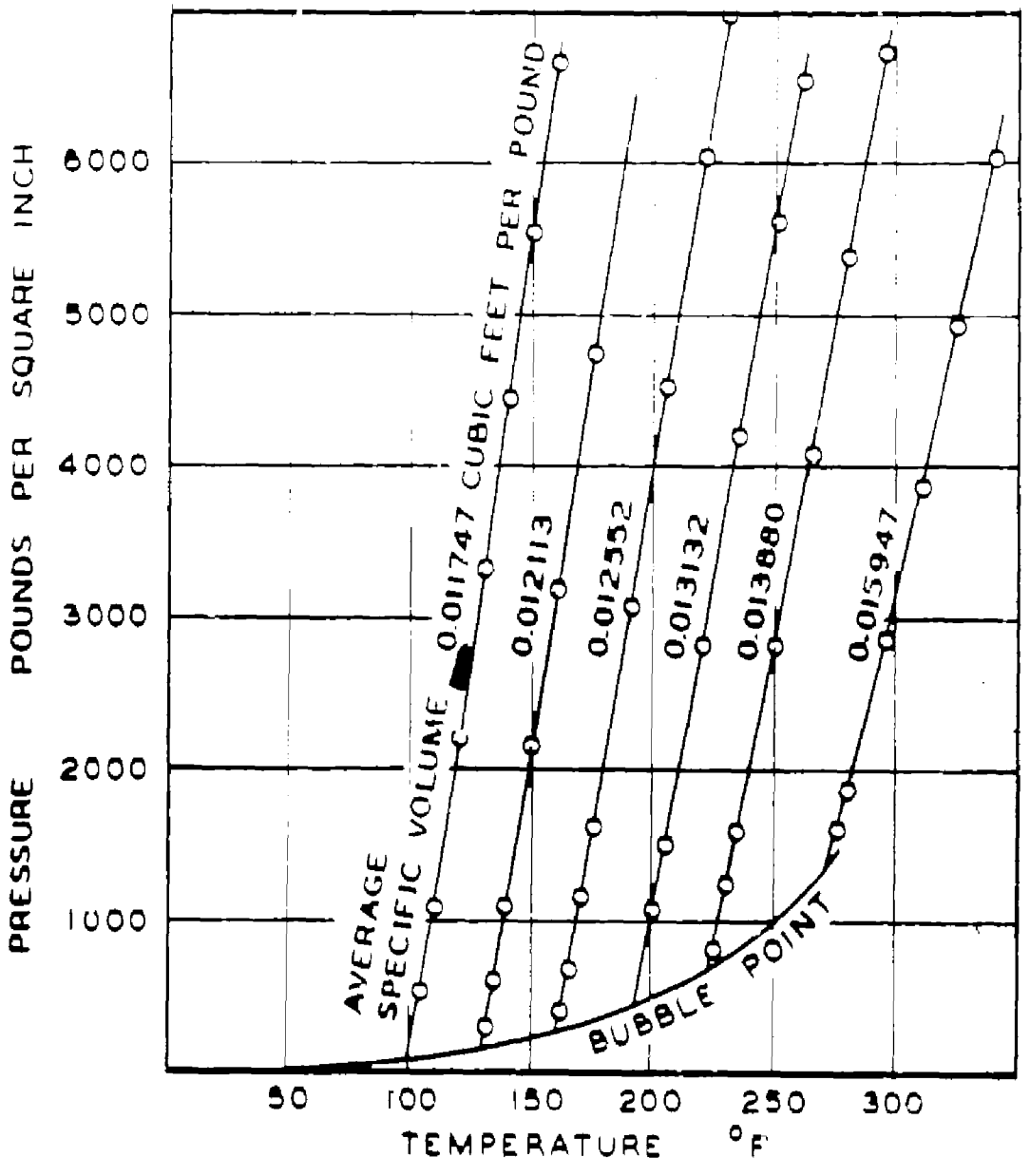

Fig. 2 Pressure-Temperature Diagram for a Mixture Containing 0.8205 Weight Fraction Nitrogen Dioxide.

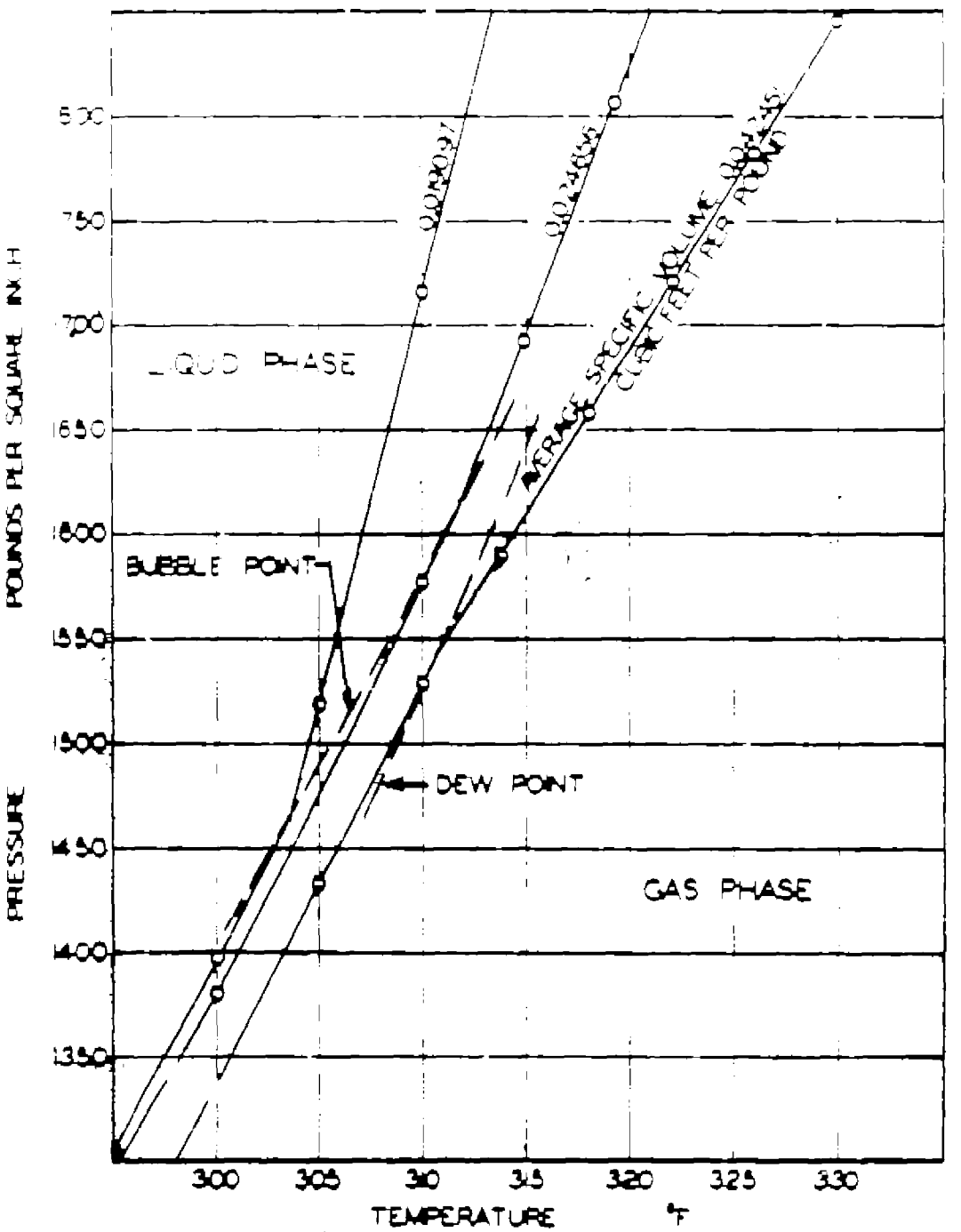

Fig. 3 Behavior of a Mixture Containing 0.9431 Weight Fraction Nitrogen Dioxide in the Heterogeneous Region.

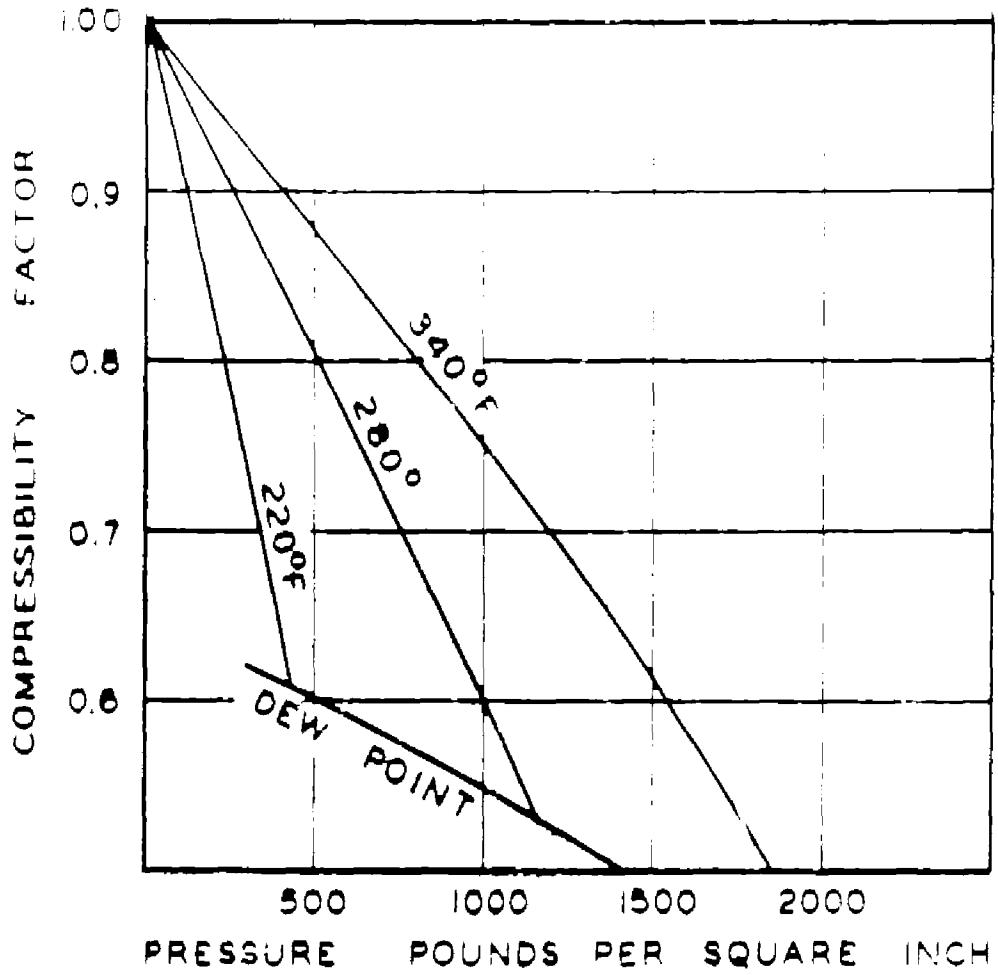

Fig. 4 Compressibility Factor for a Mixture Containing 0.8312 Weight Fraction Nitrogen Dioxide.

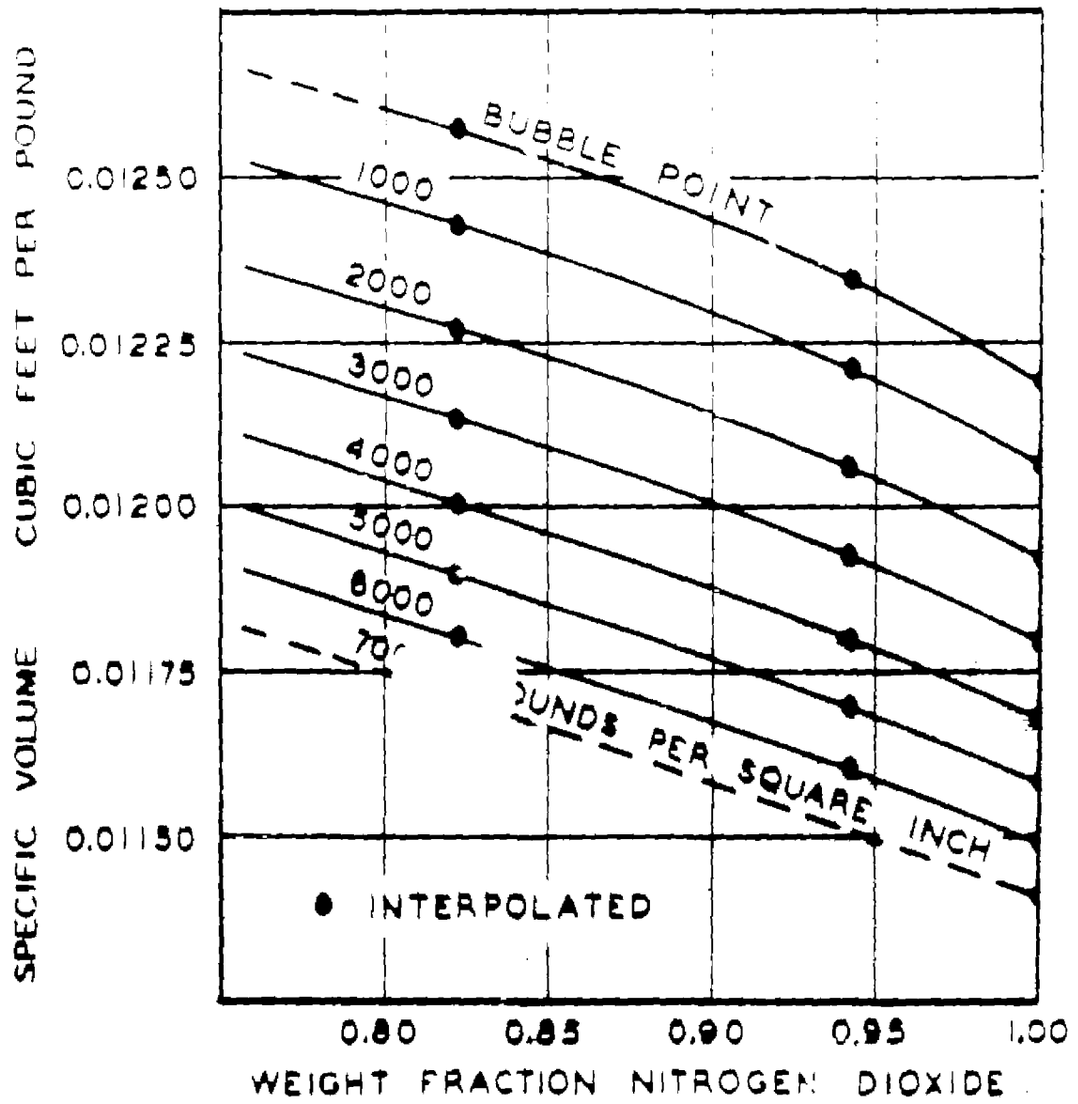

Fig. 5 Specific Volume-Composition Diagram for a Temperature of 160° F.

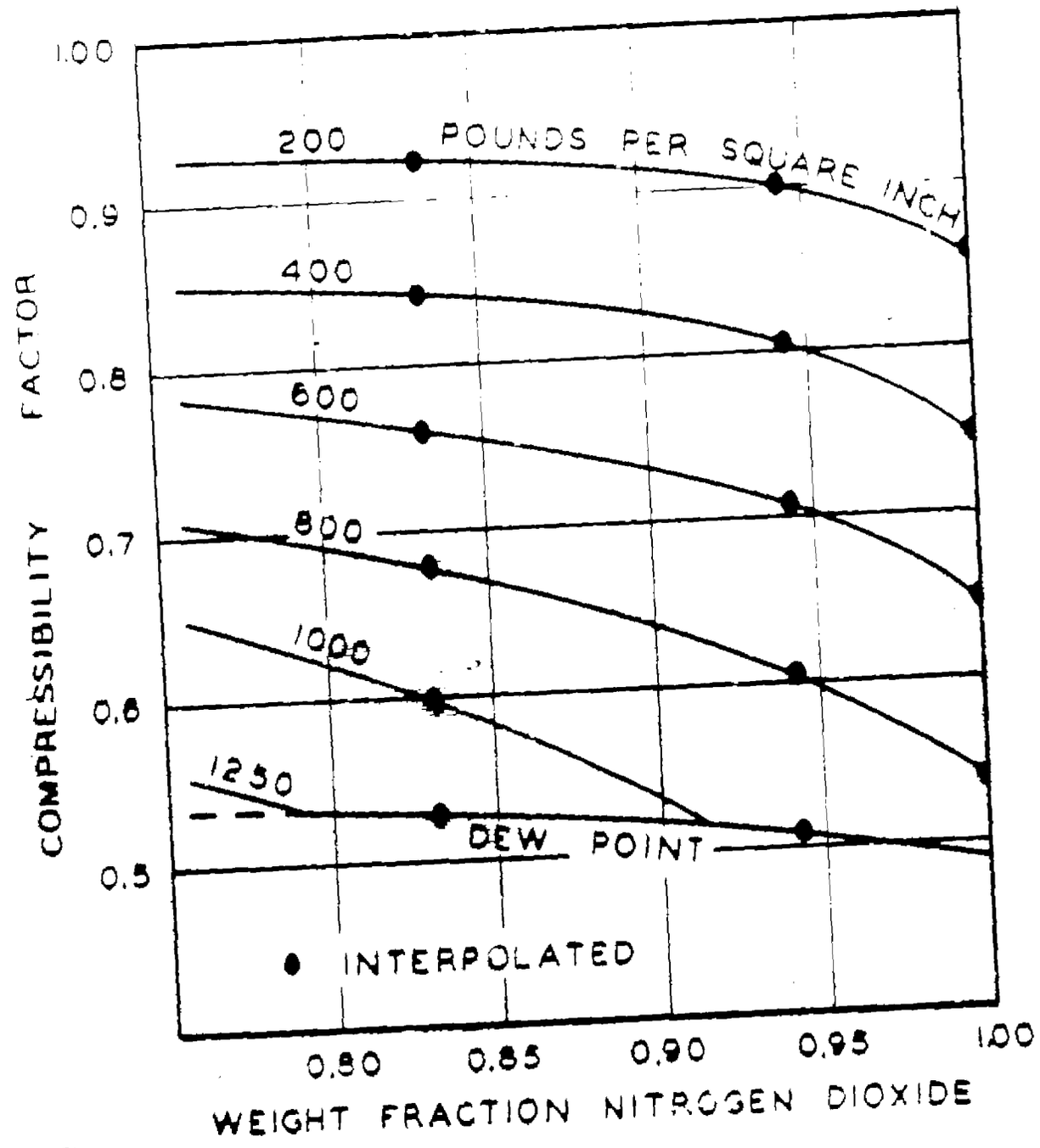

Fig. 6 Effect of Composition upon Compressibility Factor at 280° F.

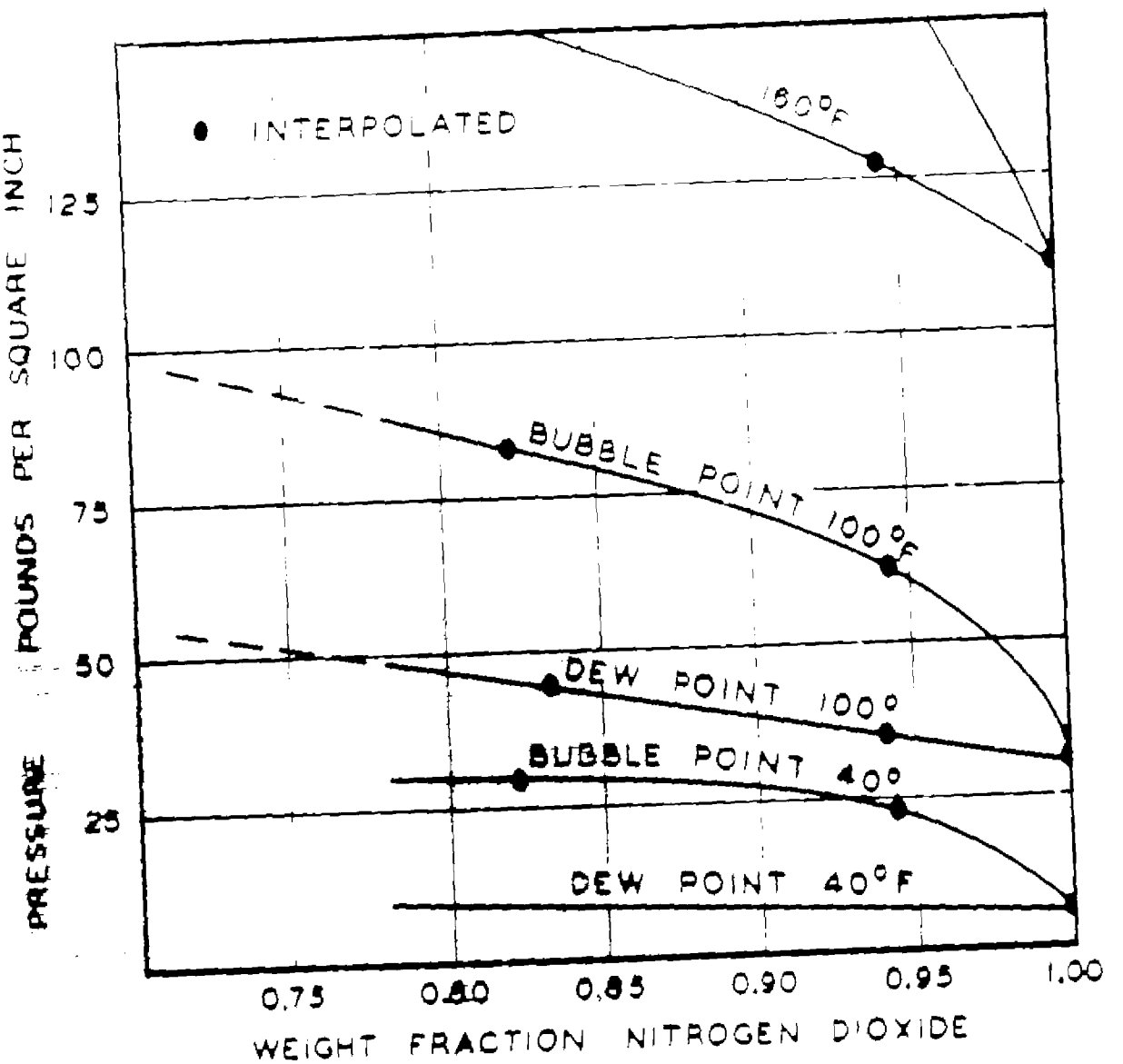

Fig. 7 Pressure-Composition Diagram for the Lower Temperatures.

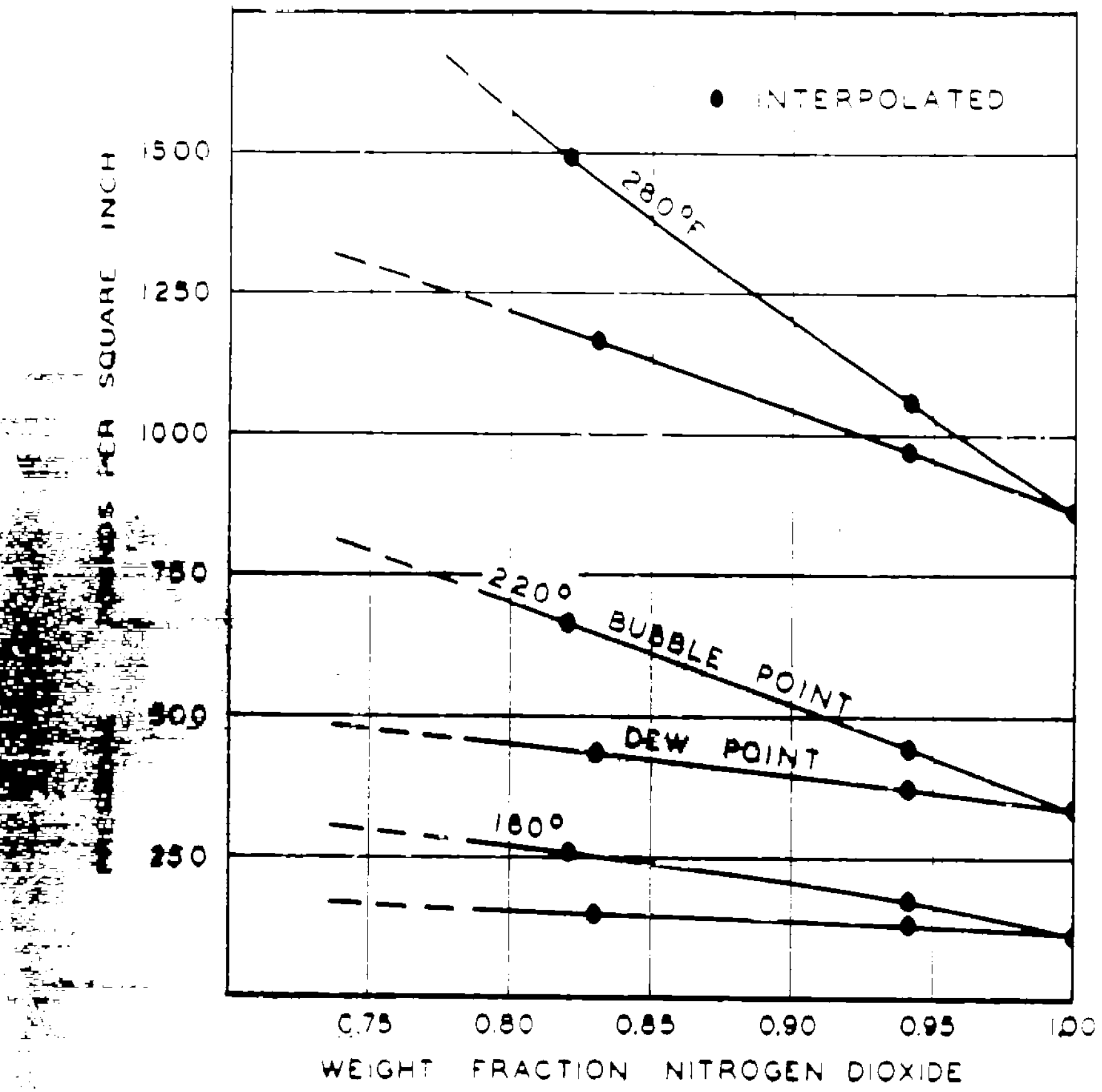

Fig. 8 Pressure-Composition Diagram for the Higher Temperatures.

TABLES

TABLE I

SAMPLE OF EXPERIMENTAL RESULTS

Weight Fraction Nitrogen Dioxide = 0.94305

Pressure, Lb./Sq. Inch Absolute	Temperature, °F.	Specific Volume, Cu. Ft./Lb.	Pressure, Lb./Sq. Inch Absolute	Temperature, °F.	Specific Volume, Cu. Ft./Lb.
Sample Weight = 0.792956 lb.			Sample Weight = 0.782572 lb.		
24.19	40.07	0.011008	31.17	55.00	0.011158
25.55	42.05	0.011009	31.73	55.00	0.011158
25.68	43.98	0.011009	34.82	59.99	0.011160
26.03	45.99	0.011010	35.25	60.01	0.011160
26.72	47.98	0.011010	36.63	64.00	0.011161
82.72	50.04	0.011011	37.08	64.00	0.011161
209.81	51.00	0.011011	149.18	66.00	0.011162
335.21	52.03	0.011012	633.56	70.01	0.011163
1336.22	60.00	0.011015	1834.21	80.00	0.011167
2576.81	70.01	0.011020	1845.75	80.23	0.011167
3824.14	80.05	0.011024	3023.12	90.00	0.011172
5044.04	90.01	0.011028	4206.07	100.00	0.011176
6263.92	100.02	0.011032	5379.52	110.01	0.011180
			7144.18	125.00	0.011187

TABLE II

VOLUMETRIC BEHAVIOR OF MIXTURES OF THE NITRIC OXIDE-NITROGEN DIOXIDE SYSTEM

Weight Fraction Nitrogen Dioxide= 0.95

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	40°F.		100°F.		160°F.	
Dew point	-	-	-	-	-	-
	(22)[a]		(60)		(162)	
Bubble point	0.01093[b]	0.0020	0.011559	0.0052	0.012326	0.0135
200	0.01092	0.0182	0.011541	0.0172	0.012319	0.0166
400	0.01090	0.0364	0.011519	0.0344	0.012288	0.0331
600	0.01089	0.0546	0.011496	0.0515	0.012256	0.0496
800	0.01088	0.0727	0.011474	0.0635	0.012224	0.0659
1000	0.01086	0.0907	0.011453	0.0854	0.012190	0.0821
1250	0.01084	0.1132	0.011429	0.1066	0.012152	0.1024
1500	0.01083	0.1357	0.011402	0.1276	0.012118	0.1225
1750	0.01081	0.1581	0.011381	0.1486	0.012081	0.1425
2000	0.01079	0.1803	0.011359	0.1695	0.012048	0.1624
2250	0.01078	0.2027	0.011338	0.1903	0.012013	0.1821
2500	0.01076	0.2248	0.011316	0.2111	0.011980	0.2018
2750	0.01074	0.2468	0.011292	0.2317	0.011946	0.2214

[a] Figures in parentheses represent dew point or bubble point pressures expressed in lb./sq. inch.

[b] Specific volumes for 40° F. are extrapolated.

[c] Specific volumes at 7000 lb./sq. inch for all temperatures are extrapolated.

TABLE II (cont.)

Weight Fraction Nitrogen Dioxide = 0.95

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	40°F.		100°F.		160°F.	
Dew point	-	-	-	-	-	-
	(22)		(60)		(162)	
Bubble point	0.01093	0.0020	0.011559	0.0052	0.012326	0.0135
3000	0.01073	0.2690	0.011268	0.2522	0.011912	0.2408
3500	0.01069	0.3126	0.011223	0.2931	0.011847	0.2794
4000	0.01066	0.3563	0.011180	0.3336	0.011781	0.3175
4500	0.01063	0.3997	0.011141	0.3740	0.011730	0.3557
5000	0.01060	0.4429	0.011106	0.4143	0.011681	0.3936
6000	0.01054	0.5284	0.011029	0.4937	0.011589	0.4686
7000	0.01048[c]	0.6130	0.010958[c]	0.5723	0.011493[c]	0.5421

TABLE II (cont.)

Weight Fraction Nitrogen Dioxide = 0.95

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	220°F.		280°F.		340°F.	
Dew point	(364) 0.2697[d]	0.6034	(953) 0.09428[d]	0.5070		
Bubble point	(424) 0.013504	0.0352	(1026) 0.016064	0.0930		
200	0.6404	0.7869	0.7945	0.8970	0.9085[e]	0.9488
400	-	-	0.3538	0.7989	0.4299	0.8979
600	0.013444	0.0496	0.2071	0.7014	0.2704	0.8473
800	0.013380	0.0658	0.1324	0.5979	0.1910	0.7980
1000	0.013320	0.0818	-	-	0.1432	0.7476
1250	0.013249	0.1017	0.015739	0.1111	0.1043	0.6833
1500	0.013181	0.1215	0.015424	0.1306	0.07743	0.6065
1750	0.013117	0.1410	0.015165	0.1498	0.05707	0.5215
2000	0.013051	0.1604	0.014944	0.1687	0.03890	0.4062
2250	0.012990	0.1796	0.014765	0.1875		
2500	0.012929	0.1986	0.014607	0.2062		
2750	0.012869	0.2174	0.014466	0.2246		
3000	0.012811	0.2361	0.014339	0.2428		
3500	0.012707	0.2732	0.014115	0.2789		
4000	0.012609	0.3099	0.013918	0.3143		
4500	0.012523	0.3462	0.013740	0.3490		
5000	0.012442	0.3822	0.013588	0.3835		
6000	0.012288	0.4530	0.013318	0.4511		
7000	0.012139[e]	0.5220	0.013090[e]	0.5173		

[d] Dew point volumes are estimated.

[e] Volumes for 340° F. are extrapolated.

TABLE II (cont.)

Weight Fraction Nitrogen Dioxide = 0.90

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	40°F.		100°F.		160°F.	
Dew point	-	-	-	-	-	-
	(27)		(71)		(204)	
Bubble point	0.01103[b]	0.0024	0.011648	0.0060	0.012431	0.0167
200	0.01102	0.01780	0.011631	0.0169	0.012431	0.0163
400	0.01100	0.0358	0.011608	0.0338	0.012396	0.0326
600	0.01099	0.0537	0.011582	0.0505	0.012361	0.0487
800	0.01097	0.0715	0.011561	0.0672	0.012328	0.0648
1000	0.01096	0.0893	0.011539	0.0839	0.012293	0.0807
1250	0.01094	0.1114	0.011511	0.1046	0.012252	0.1006
1500	0.01092	0.1334	0.011488	0.1253	0.012213	0.1203
1750	0.01090	0.1554	0.011463	0.1459	0.012178	0.1400
2000	0.01089	0.1774	0.011441	0.1664	0.012141	0.1595
2250	0.01087	0.1992	0.011418	0.1868	0.012104	0.1789
2500	0.01085	0.2209	0.011397	0.2072	0.012069	0.1982
2750	0.01083	0.2426	0.011372	0.2274	0.012035	0.2174
3000	0.01081	0.2642	0.011350	0.2476	0.012000	0.2364
3500	0.01078	0.3073	0.011307	0.2878	0.011938	0.2514
4000	0.01075	0.3502	0.011259	0.3275	0.011872	0.3119
4500	0.01072	0.3929	0.011218	0.3671	0.011819	0.3493
5000	0.01068	0.4350	0.011182	0.4066	0.011770	0.3865
6000	0.01061	0.5185	0.011106	0.4846	0.011674	0.4600
7000	0.01055[c]	0.6015	0.011029[c]	0.5614	0.011579[c]	0.5323

TABLE II (cont.)

Weight Fraction Nitrogen Dioxide: 0.90

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	220°F.		280°F.		340°F.	
		(394)		(1043)		
Dew point	0.2592[d]	0.6110	0.09042[d]	0.5188		
		(516)		(1201)		
Bubble point	0.013640	0.0421	0.016283	0.1132		
200	0.6784	0.8125	0.8303	0.9137	0.9373[e]	0.9541
400	-	-	0.3760	0.8275	0.4460	0.9079
600	0.013608	0.0489	0.2221	0.7334	0.2822	0.8619
800	0.013531	0.0648	0.1449	0.6379	0.2007	0.8172
1000	0.013467	0.0806	0.09805	0.5395	0.1515	0.7711
1250	0.013387	0.1002	0.016209	0.1115	0.1119	0.7120
1500	0.013317	0.1196	0.015851	0.1308	0.08446	0.6448
1750	0.013249	0.1388	0.015525	0.1495	0.06413	0.5712
2000	0.013182	0.1579	0.015257	0.1679	0.04724	0.4809
2250	0.013119	0.1768	0.015036	0.01862		
2500	0.013059	0.1955	0.014848	0.2042		
2750	0.013000	0.2141	0.014687	0.2222		
3000	0.012944	0.2325	0.014542	0.2400		
3500	0.012838	0.2690	0.014310	0.2756		
4000	0.012739	0.3051	0.014106	0.3105		
4500	0.012650	0.3409	0.013921	0.3447		
5000	0.012568	0.3763	0.013758	0.3785		
6000	0.012408	0.4458	0.013478	0.4450		
7000	0.012257[c]	0.5138	0.013231[c]	0.5096		

TABLE II (Cont.)

Weight Fraction Nitrogen Dioxide = 0.85

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	40°F.		100°F.		160°F.	
Dew point	-	-	-	-	-	-
	(29)		(79)		(239)	
Bubble point	0.01113[b]	0.0026	0.011736	0.0066	0.012527	0.0192
200	0.01112	0.0177	0.011720	0.0166	-	-
400	0.01110	0.0353	0.011700	0.0332	0.012491	0.0320
600	0.01109	0.0528	0.011669	0.0496	0.012455	0.0479
800	0.01107	0.0704	0.011643	0.0660	0.012419	0.0636
1000	0.01105	0.0878	0.011619	0.0824	0.012381	0.0793
1250	0.01103	0.1095	0.011590	0.1027	0.012340	0.0988
1500	0.01101	0.1312	0.011562	0.1230	0.012299	0.1182
1750	0.01099	0.1528	0.011539	0.1432	0.012262	0.1374
2000	0.01097	0.1743	0.011511	0.1633	0.012228	0.1566
2250	0.01095	0.1957	0.011489	0.1833	0.012190	0.1757
2500	0.01093	0.2171	0.011466	0.2033	0.012157	0.1947
2750	0.01091	0.2393	0.011441	0.2231	0.012121	0.2135
3000	0.01089	0.2595	0.011419	0.2430	0.012089	0.2323
3500	0.01086	0.3020	0.011376	0.2824	0.012026	0.2696
4000	0.01082	0.3438	0.011329	0.3214	0.011961	0.3065
4500	0.01079	0.3857	0.011289	0.3603	0.011905	0.3432
5000	0.01075	0.4270	0.011251	0.3990	0.011853	0.3796
6000	0.01068	0.5090	0.011175	0.4755	0.011759	0.4520
7000	0.01061[c]	0.5900	0.011100[c]	0.5511	0.011664[c]	0.5236

TABLE II (cont.)

Weight Fraction Nitrogen Dioxide = 0.85

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb. 220°F.	Compressibility Factor	Specific Volume, Cu. Ft./Lb. 260°F.	Compressibility Factor	Specific Volume, Cu. Ft./Lb. 340°F.	Compressibility Factor
Dew point	0.2471[d] (422)	0.6087	0.08671[d] (1132)	0.5268		
Bubble point	0.013765 (610)	0.0490	0.016611 (1388)	0.1237		
200	0.7028	0.8209	0.8589	0.9219	0.9651[e]	0.9581
400	0.2705	0.6320	0.3914	0.8402	0.4611	0.9156
600	-	-	0.2344	0.7547	0.2932	0.8731
800	0.013685	0.0639	0.1561	0.6700	0.2092	0.8309
1000	0.013609	0.0795	0.1088	0.5841	0.1588	0.7882
1250	0.013525	0.0987	-	-	0.1182	0.7331
1500	0.013449	0.1178	0.016341	0.1315	0.09048	0.6737
1750	0.013579	0.1388	0.016916	0.1589	0.07018	0.6096
2000	0.013311	0.1555	0.015579	0.1672	0.05299	0.5251
2250	0.013251	0.1741	0.015309	0.1848		
2500	0.013189	0.1926	0.015094	0.2025		
2750	0.013130	0.2109	0.014914	0.2201		
3000	0.013072	0.2290	0.014761	0.2376		
3500	0.012967	0.2650	0.014511	0.2726		
4000	0.012869	0.3006	0.014300	0.3070		
4500	0.012778	0.3358	0.014118	0.3409		
5000	0.012689	0.3705	0.013948	0.3743		
6000	0.012527	0.4390	0.013641	0.4392		
7000	0.012378[c]	0.5060	0.013389[c]	0.5030		

TABLE II (cont.)

Weight Fraction Nitrogen Dioxide = 0.80

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	40°F.		100°F.		160°F.	
Dew point	-	-	-	-	-	-
	(30)		(86)		(270)	
Bubble point	0.01125[b]	0.0026	0.011828	0.0070	0.012666	0.0215
200	0.01123	0.01741	0.011810	0.0163	-	-
400	0.01120	0.0347	0.011781	0.0326	0.012578	0.0314
600	0.01118	0.0520	0.011758	0.0488	0.012538	0.0470
800	0.01116	0.0692	0.011730	0.0650	0.012499	0.0625
1000	0.01115	0.086	0.011737	0.0810	0.012461	0.0779
1250	0.01112	0.1078	0.011676	0.1010	0.012419	0.0970
1500	0.01110	0.1291	0.011649	0.1209	0.012378	0.1161
1750	0.01108	0.1503	0.011620	0.1407	0.012339	0.1350
2000	0.01106	0.1715	0.011590	0.1604	0.012302	0.1538
2250	0.01104	0.1926	0.011566	0.1801	0.012268	0.1726
2500	0.01102	0.2136	0.011539	0.1997	0.012232	0.1912
2750	0.01100	0.2345	0.011512	0.2191	0.012199	0.2097
3000	0.01098	0.2554	0.011489	0.2386	0.012168	0.2282
3500	0.01095	0.2971	0.011438	0.2771	0.012104	0.2648
4000	0.01091	0.3383	0.011391	0.3154	0.012041	0.3011
4500	0.01087	0.3792	0.011358	0.3538	0.011988	0.3372
5000	0.01083	0.4198	0.011320	0.3917	0.011939	0.3732
6000	0.01076	0.5005	0.011246	0.4670	0.011839	0.4441
7000	0.01068[c]	0.5796	0.011170[c]	0.5412	0.011742[c]	0.5138

TABLE II (cont.)

Weight Fraction Nitrogen Dioxide = 0.80

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	220°F.		280°F.		340°F.	
Dew point	0.2340[d] (449)	0.5987	0.08338[d] (1217)	0.5315		
Bubble point	0.013871 (701)	0.0554	0.017075 (1570)	0.1404		
200	0.7223	0.8234	0.8840	0.9259	0.9917[e]	0.9668
400	0.2841	0.6476	0.4043	0.8469	0.4753	0.9209
600	-	-	0.2451	0.7762	0.3031	0.8810
800	0.013830	0.0531	0.1656	0.6939	0.2169	0.8406
1000	0.013749	0.0784	0.1183	0.6198	0.1653	0.8008
1250	0.013658	0.0973	-	-	0.1237	0.7492
1500	0.013574	0.1160	-	-	0.09576	0.6958
1750	0.013500	0.1346	0.016391	0.1502	0.07525	0.6378
2000	0.013431	0.1531	0.015938	0.1669	0.06054	0.5865
2250	0.013371	0.1715	0.015601	0.1838		
2500	0.013312	0.1897	0.015350	0.2010		
2750	0.013253	0.2077	0.015150	0.2182		
3000	0.013199	0.2257	0.014989	0.2355		
3500	0.013089	0.2611	0.014721	0.2698		
4000	0.012990	0.2962	0.014509	0.3039		
4500	0.012900	0.3309	0.014318	0.3374		
5000	0.012816	0.3652	0.014146	0.3704		
6000	0.012651	0.4326	0.013831	0.4346		
7000	0.012498[c]	0.4986	0.013560[c]	0.4971		

TABLE II (cont.)

Weight Fraction Nitrogen Dioxide – 0.75[f]

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	40°F.		100°F.		160°F.	
Dew point	-	-	-	-	-	-
	(30)		(93)		(288)	
Bubble point	0.01134[b]	0.0026	0.011923	0.0075	0.012679	0.0223
200	0.01132	0.0171	0.011902	0.0161	-	-
400	0.01130	0.0342	0.011873	0.0321	0.012651	0.0309
600	0.01128	0.0512	0.011847	0.0480	0.012609	0.0462
800	0.01125	0.0682	0.011819	0.0639	0.012571	0.0614
1000	0.01124	0.0851	0.011791	0.0797	0.012532	0.0765
1250	0.01122	0.1062	0.011759	0.0993	0.012490	0.0954
1500	0.01119	0.1271	0.011728	0.1189	0.012450	0.1140
1750	0.01117	0.1480	0.011698	0.1384	0.012412	0.1326
2000	0.01114	0.1687	0.011669	0.1577	0.012379	0.1511
2250	0.01112	0.1894	0.011640	0.1770	0.012345	0.1696
2500	0.01110	0.2101	0.011611	0.1962	0.012313	0.1879
2750	0.01107	0.2304	0.011582	0.2153	0.012280	0.2061
3000	0.01106	0.2512	0.011558	0.2343	0.012248	0.2243
3500	0.01102	0.2920	0.011510	0.2723	0.012181	0.2602
4000	0.01098	0.3325	0.011461	0.3098	0.012119	0.2959
4500	0.01094	0.3727	0.011424	0.3474	0.012062	0.3313
5000	0.01094	0.4141	0.011389	0.3844	0.012011	0.3666
6000	0.01082	0.4914	0.011312	0.4587	0.011918	0.4365
7000	0.01074[c]	0.5691	0.011232[c]	0.5314	0.011827[c]	0.5054

[f] All values of volume for this composition are extrapolated.

TABLE II (cont)

Weight Fraction Nitrogen Dioxide- 0.75

Pressure, Lb./Sq. Inch Absolute	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor	Specific Volume, Cu. Ft./Lb.	Compressibility Factor
	270°F.		280°F.		340°F.	
	(475)		(1312)			
Dew point	0.2199[d]	0.5813	0.0795[d]	0.5335		
	(790)		(1643)			
Bubble point	0.013980	0.0615	0.017619	0.1480		
200	0.7411	0.8249	0.9072	0.9279	1.017[e]	0.9619
400	0.2955	0.5579	0.4164	0.8518	0.4884	0.9242
600	-	-	0.2546	0.7812	0.3122	0.8861
800	0.013978	0.0622	0.1741	0.7125	0.2241	0.8480
1000	0.013889	0.0773	0.1263	0.6459	0.1712	0.8099
1250	0.013790	0.0959	0.0875	0.5591	0.1290	0.7625
1500	0.013705	0.1144	-	-	0.1005	0.7129
1750	0.013626	0.1327	0.017058	0.1527	0.07975	0.6606
2000	0.013551	0.1508	0.016401	0.1678	0.06418	0.6072
2250	0.013491	0.1689	0.015949	0.1835		
2500	0.013431	0.1869	0.015629	0.1998		
2750	0.013372	0.2046	0.015401	0.2166		
3000	0.013319	0.2224	0.015224	0.2336		
3500	0.013215	0.2574	0.014941	0.2674		
4000	0.013116	0.2920	0.014713	0.3010		
4500	0.013029	0.3263	0.014521	0.3342		
5000	0.012943	0.3602	0.014346	0.3668		
6000	0.012781	0.4268	0.014022	0.4302		
7000	0.012619	0.4916	0.013732	0.4916		

TABLE III

PROPERTIES OF THE COEXISTING PHASES IN THE NITRIC OXIDE-NITROGEN DIOXIDE SYSTEM

Pressure, Lb. Sq. Inch Absolute	Weight Fraction Nitrogen Dioxide		Specific Volume, Cu. Ft./Lb.	
	Dew Point	Bubble Point	Dew Point	Bubble Point
		40°F.		
6.5[a]	1.0000	1.0000	1.156	0.01034
8.0	0.8745	0.9956	-	0.01034
9.0	0.8015	0.9931	-	0.01034
10.0	0.762	0.9907	-	0.01035
15.0	-	0.9770	-	0.01038
20.0	-	0.9588	-	0.01041
25.0	-	0.9274	-	0.01047
		100°F.		
30.7[a]	1.0000	1.0000	2.5190	0.011439
35.0	0.9454	0.9958	-	0.011449
40.0	0.8845	0.9901	-	0.011461
45.0	0.8272	0.9832	-	0.011479
50.0	0.7706	0.9750	-	0.011500
60.0	-	0.9504	-	0.011557
70.0	-	0.9073	-	0.011635
80.0	-	0.8421	-	0.011750
90.0	-	0.7701	-	0.011881
		160°F.		
111.2[a]	1.0000	1.0000	4.7733	0.012188
120.0	0.9701	0.9920	-	0.012211
130.0	0.9329	0.9824	-	0.012239
140.0	0.8870	0.9729	-	0.012264
150.0	0.8311	0.9625	-	0.012290
175.0	-	0.9354	-	0.012336
200.0	-	0.9052	-	0.012422
225.0	-	0.8714	-	0.012488
250.0	-	0.8331	-	0.012553
275.0	-	0.7867	-	0.012622

[a] Vapor pressure of nitrogen dioxide

[b] Dew point volumes are estimated

TABLE II (cont.)

Pressure, Lb./Sq. Inch Absolute	Weight Fraction Nitrogen Dioxide		Specific Volume, Cu. Ft./Lb.	
	Dew Point	Bubble Point	Dew Point	Bubble Point
		220°F.		
332.8[a]	1.0000	1.0000	0.2743	0.013343
350.0	0.9728	0.9899	0.2733[b]	0.013373
375.0	0.9319	0.9767	0.2654	0.013413
400.0	0.8887	0.9631	0.2566	0.013460
425.0	0.8438	0.9498	0.2457	0.013505
450.0	0.7978	0.9361	0.2334	0.013544
500.0	-	0.9091	-	0.013619
600.0	-	0.8549	-	0.013761
700.0	-	0.8003	-	0.013870
		280°F.		
864.1[a]	1.0000	1.0000	0.0984	0.015924
900.0	0.9797	0.9884	0.0968[b]	0.015949
950.0	0.9518	0.9730	0.0943	0.015990
1000.0	0.9240	0.9575	0.0905	0.016037
1050.0	0.8959	0.9428	0.0900	0.016092
1100.0	0.8678	0.9282	0.0888	0.016149
1200.0	0.8103	0.9002	0.0840	0.016282
1300.0	-	0.8733	-	0.016447
1400.0	-	0.8467	-	0.016639
1500.0	-	0.8298	-	0.016780